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EVALUATION OF THE PERFORMANCE OF THE AQUA LUNG SELF CONTAINED SWIMMING OUTFIT AS FURNISHED AND ALSO WHEN IT IS MODIFIED BY THE SUBSTITUTION OF THE MOUTHPIECE FOR A FACE MASK.

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OBJECT

The object of this experiment is to evaluate the performance of the Aqua-Lung self contained swimming outfit as furnished and also when it is modified by the substitution of the mouthpiece for a face mask.

PROCEDURE

The Aqua-Lung consists of three connected air tanks fitted with a demand regulator. Two corrugated breathing hoses are hooked to the demand breathing regulator, both of which lead to the mouthpiece. One is the inhalation and the other is the exhalation hose. The exhalation hose terminates at the demand valve to balance the hydrostatic pressure of inhalation and exhalation during changes of position of the swimmer. A mask covering the eyes and nose is provided. In our experiments, a nose clip and goggles were found to be more comfortable and these were used throughout the tests.

The steel cylinders were about 24 inches long and about 5 inches in diameter. The volume of each cylinder was about 400 cubic inches. The working pressure was 2100 psi. The three cylinders were held in place by means of a canvas harness. The outfit is fitted with an air reserve device. When the pressure in the cylinders drops to 300 psi, the swimmer experiences some difficulty in breathing, which warns him that the air supply is getting low. When the air reserve valve is opened, normal breathing is restored and the swimmer can then surface. This unit is a product of Space Inc., New York, New York. It was formerly known as the Cousteau Cagnon outfit.

Tests were conducted at atmospheric, 33, 66, and 99 foot depths with this apparatus under rest and work conditions. The mouthpiece was then removed and replaced with a full face mask. This mask was made by the Mine Safety Appliance Company. Tests were then conducted at atmospheric, 33, 66, and 99 foot depths at rest and work conditions. Three runs were made with each outfit under these conditions.

A run consisted of each subject making a dive for fifteen minutes. At rest the subject sat or moved only when uncomfortable. A work run consisted of 5 minutes of work, 5 minutes rest and 5 minutes work. Work consisted of lifting a weight, weighing 68.5 pounds submerged, a distance of 27.25 inches 10 times per minute.

Samples were taken at the end of the 15 minute run. These were obtained by inserting a Luer needle in the area near the nostrils and extracting the sample at inspiration.

All controlled tests were made in the pressure tank. The water was usually at a temperature of 85 to 90 degrees F. The pressure in the bank of air bottles was taken before and after each run. The difference represented the amount used.

Tests were also made to determine the performance of the reserve air device. Measurement of the amount of air at standard conditions for a certain pressure dro were made by exhausting the bottles through a meter.

Three swimming tests were made with each outfit in a swimming pool under rest and swimming conditions to determine the swimming characteristics.

A trial run was made with inhalation and exhalation check valves in the syst but the added breathing resistance made this impractical.

RESULTS AND DISCUSSION

The CO_2 samples indicate that none of the dives were in the danger zone, that is, 3% effective or over. Most of the samples were under 1% effective. The Aqua-Lung with the mouthpiece showed a consistent lower CO_2 than when the MSA mask was used. This is as expected since the dead air space in the mask is considerably greater. The dead air space in the outfit with the mouthpiece consists merely of the volumes of the inhalation and exhalation tubes. When the face mask is used, the dead air space consists of the two tubes plus the unoccupied space of the mask. Obviously, a greater CO_2 is to be expected in the latter case since a greater volume of the expired air is breathed. However, in no case was there a dangerous effective concentration. The attempt to reduce the dead air space in the outfit with the face mask by the installation of check valves at the mask end of the breathing tubes was unsuccessful because of the greatly increased breathing resistance. In all the dives, the subjects experience no symptoms of excessive CO_2 concentration. The CO_2 problem in the case of the mouthpiece is practically non-existent since except for the dead air space in the inhalation and exhalation tubes, all of the inspired air is pure. Attention is invited to the vacillation in the CO_2 samples. This is expected because of the sampling method. It was taken in the area below the nostrils at inspiration and the difficulty of obtaining a representative sample is obvious. However, it is significant that in no case was there a dangerous effective concentration in the mask in the area of inspiration. The samples were always taken at the end of dive when the CO_2 output would be greatest.

There is some difference between the amount of air used with the two outfits. The outfit with the mouthpiece uses less air, but in general the difference is not too significant. The differences maybe also due to the individual differences of the lung capacities of the diver. The data sheets should be examined for the duration of the outfit under rest and work conditions. The duration is great enough to make the outfit practical. These results are based on the assumption that the bottles are filled to 2100 psi and that diving operations are to cease when the bottles reach a pressure of 300 psi. It is important to notice that decompression time is not included. The work performed in these tests is roughly equivalent to moderate swimming of trained subjects. More air would be used under duress and with subjects that have had little experience in the use of these outfits. The time limit of the outfit should be equal to that time where no decompression is required at that particular depth. A diver with a small lung capacity and under conditions of little activity would require recompression before exhaustion of the air supply. The rate of ascent should not exceed 25 feet per minute.

All of the subjects unanimously preferred the Aqua-Lung with the MSA mask. The use of the mouthpiece was objectionable for even this short period of 15 minutes. There is also the danger of losing the mouthpiece. Replacement of it would be difficult if not impossible. Most subjects agreed that the harness was unsatisfactory and especially so when working. A jock strap was also suggested by many to make the outfit more wearable. Swimming was satisfactory from a buoyancy standpoint and good control and speed were possible when swim fins were used. In salt water, the buoyancy of the diver would increase. A weighed belt would be necessary if the diver is to work on the bottom. Obviously, the bottles do become lighter as the air is being used. A fully charged set of bottl weighs about 5 pounds more than when they are empty. Some of the subjects though that the breathing resistance became noticeable after some time. Tests with a demand appliance that has less resistance are suggested.

This may not prove practical because a position that would place the demand valve below the center line of the chest would produce continuous flow. The great advantage of the Aqua-Lung is that there is no danger of oxygen poisoning. as in other self contained outfits using oxygen, although it is clumsier and leaves bubbles on the surface. Charging the bottles to 2100 psi might be a major problem in some areas. It would also serve well as an emergency diving outfit. These outfits should be limited to a depth of 60 feet.

A pressure drop of 560 psi produced a volume of 750 liters at atmospheric conditions. This would give 134 liters of air at atmospheric pressure for each 100 psi pressure drop.

The reserve air device performed satisfactorily at all depths.

It is suggested that this outfit be used only in open work where direct ascent to the surface is possible. A fouled diver might prove to be a fatality because of the limited air supply. In addition, the cumbersome air tanks predispose to fouling in tight places.

The demand valve is held together by means of metal clips. Upon disassembly these are expanded. When the valve is again assembled, these clips fail to hold the component parts securely enough to prevent leakage. The use of the bolts or screws to secure the flanges is suggested.

CONCLUSIONS

The Aqua-Lung is safe with regard to effective CO_2 with either the mouthpiece or the MSA mask up to depths of 99 feet under moderate work conditions The outfit with the mouthpiece showed consistently lower CO_2.

The MSA mask is overshelmingly superior to the mouthpiece from a standpoint of comfort, visibility and safety.

The harness should be revised and the possibility of adding a jock strap should be investigated.

The swimming characteristics of the outfit were satisfactory with swim fins, although weights would be necessary to perform work.

The breathing resistance became noticeable after work and a demand valve with less resistance is indicated.

The equipment is rugged and simple and would require a minimum of maintenance. The clips used to secure the flanges in the demand valve are unsatisfactory.

The time limit for a particular depth should be the time where no decompression is required.

The maximum depth should not exceed 60 feet with a rate of ascent not greater than 25 feet per minute.

RECOMMENDATIONS

It is recommended that the MSA face mask supplant the mouthpiece. This outfit should then be submitted to the activity concerned for further trials in the field.

It is recommended that experiments be conducted with other demand valves to determine whether a reduction in breathing resistance is possible.

It is recommended that a more comfortable harness be constructed with the possible addition of a jock strap.

It is recommended that the time limit for a particular depth should be the time where no decompression is required.

It is recommended that the maximum depth for these outfits be limited to 60 feet with a rate of ascent not greater than 25 feet per minute.

It is recommended that these outfits be used only in unconfined spaces with direct ascent to the surface.

It is recommended that bolts or screws be substituted for the clips in the demand valve.

AQUA LUNG WITH MOUTHPIECE AT REST

Depth Ft.	Surface			33			66			99	
Run No.	1	2	3	1	2	3	1	2	3	1	2
Effective CO2 %	.502	.369	.618	.142	.092	.456	.135	.369	.033	.224	.092
Total Air Used PSI	440			780			1360			995	

AQUA LUNG WITH MOUTHPIECE AT WORK

Depth Ft.	Surface			33			66			99	
Run no.	1	2	3	1	2	3	1	2	3	1	2
Effective CO2 %	.242	.046	.322	.046	.166	.664	.255	.069	.135	.408	1.68
Total Air Used PSI	735			1375			2085			1550	

AQUA LUNG WITH MASK AT REST

Depth Ft.	Surface			33			66			99		
Run No.	1	2	3	1	2	3	1	2	3	1	2	3
Effective CO2 %	1.47	3.16	.82	1.09	1.83	2.01	1.18	.55	.13	.416	.392	.428
Total Air Used PSI	500			715			1600			1985		

AQUA LUNG WITH MASK AT WORK

Depth Ft.	Surface			33			66			99		
Run No.	1	2	3	1	2	3	1	2	3	1	2	3
Effective CO2 %	.115	.357	.089	2.20	.98	1.37	1.73	.80	.93	.736	.736	.652
Total Air Used PSI	1070			1385			2270			3600		

DURATION OF OUTFIT

Type of Activity	Rest				Work			
Depth (Ft)	Surface	33	66	99	Surface	33	66	99
Time (Min)	171	108	55	49	90	59	37	28
Maximum Time of Dive Without Decompression	None	None	43	25	None	None	43	25